EVALUATION OF LOAD TRANSFER DEVICES

FINAL REPORT

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SUMMARY

This report describes the procedures and findings of a study conducted by the Louisiana Department of Highways to evaluate two types of load transfer devices currently used in Portland Cement Concrete Pavements (PCC) in this state. The two devices evaluated were steel dowel bars and starlugs, a patented load transfer device. The comparison presented here is statistical in nature and was accomplished by evaluating existing concrete roadways with 58.5-foot (17.8-m), 30-foot (9.1-m), and 20-foot (6.1-m) slabs of similar age, cumulative traffic loading, and physical characteristics. The two primary aspects considered for evaluation were: (1) measurement of load transfer capability by deflection analysis, and (2) physical measurement of all major pavement deterioration. The report further relates construction problems associated with each device, as well as the results of a questionnaire sent to highway field engineers.

It is concluded that, for a given slab length, the highway projects built with dowel bars exhibited less faulting, better load transfer across joints, and relatively less pavement deterioration than those built with starlugs. Generally, however, the magnitude of faulting and load transfer measurements does not indicate a low level of performance on projects with the 20-foot (6.1-m) or 58.5-foot (17.8-m) slab length. The pavement deterioration indicates a more significant measurable difference in the performance of projects built with starlugs and dowel bars. Since the beginning of the study several conditions have arisen which limit the relevancy of the findings, they are: (1) the unavailability of projects with the 20-foot (6.1-m) joint spacing which could be paired according to like parameters (traffic, materials, etc.) as was possible for projects with the 58.5-foot (17.8-m) spacing; (2) the current use by the Louisiana Department of Highways of the 20-foot (6.1-m) slab length in lieu of the 58.5-foot (17.8-m) length; and (3) the fact that the load transfer devices evaluated were

preset prior to placement of concrete as opposed to the current methods of mechanical placement.

On the basis of the analysis of questionnaires sent to construction engineers with experience in portland cement concrete construction, it can be inferred that dowel bars are far less susceptible to construction oriented problems than are the corresponding starlugs.

Random coring and visual observations of starlugs and dowel bars indicated that no major corrosion of these devices exists on Louisiana highways. Joints with one-inch (2.5-cm) dowel bars exhibited good load transfer and minimal faulting, indicating that dowel bars with larger diameters are not warranted for use in this state.

Concrete pavements with the 20-foot (6.1-m) slabs are performing much better than those with the 58.5-foot (17.8-m) slabs.

It is recommended that the distress mechanisms evaluated for the two load transfer devices be correlated with the maintenance efforts required on the paired projects in this study, and that an effort be directed to the continued evaluation of the devices for 20-foot (6.1-m) slabs. It is further recommended that a comparison of machine placement and hand placement be conducted to determine the most effective method of installation.

INTRODUCTION

The construction and performance of transverse joints in PCC pavements has been a source of problems for highway engineers since joints were first formed in Louisiana in the 1920's. Pavement joints with no mechanism for transferring load between slabs have traditionally experienced such failures as slab faulting and mud pumping, especially where unstabilized bases were used. State highway departments throughout the country have experimented with varying methods of transferring load across transverse pavement joints. Louisiana first used steel dowel bars to connect concrete slabs and, in the early 1940's adopted the starlug (a patented load transfer device) as an alternate. Both starlugs and dowel bars have been extensively used since that time.

This report is limited to a statistical comparison of starlugs and dowel bars and an examination of the effectiveness of each as determined by the evaluation of existing concrete roadways. Load transfer capability and pavement deterioration were the primary variables measured for comparison. The report also relates construction problems associated with each device, as well as the results of a questionnaire sent to highway engineers with construction experience in Louisiana. A sample questionnaire may be found in the Appendix as Figure 18.

It is beyond the scope of this study to determine the extent to which frozen or misaligned load transfer devices are responsible for the various types of pavement deterioration presented in this report. All cracking and patching data is presented, however, to reflect the overall performance of these highways.

One of the drawbacks in the experimental design involving 20-foot (6.1-m) joint spacing sections was the unavailability of projects that could be paired according to like parameters (traffic, material, etc.) as was possible for projects with 58.5-foot

(17.8-m) joint spacings. Additionally there is the consideration that the current Louisiana Department of Highways concrete pavement design has incorporated the 20-foot (6.1-m) spacing in lieu of the 58.5-foot (17.8-m) spacing. The projects evaluated in this study contained load transfer devices which were preset prior to the placement of concrete. The primary method of installation currently being used in Louisiana, however, is mechanical placement of the devices.

The fifteen highway projects evaluated well represent Louisiana conditions and include Interstate and primary highways as well as highways through urban areas. The locations of these highways may be found in Figure 1 and in Table 1.

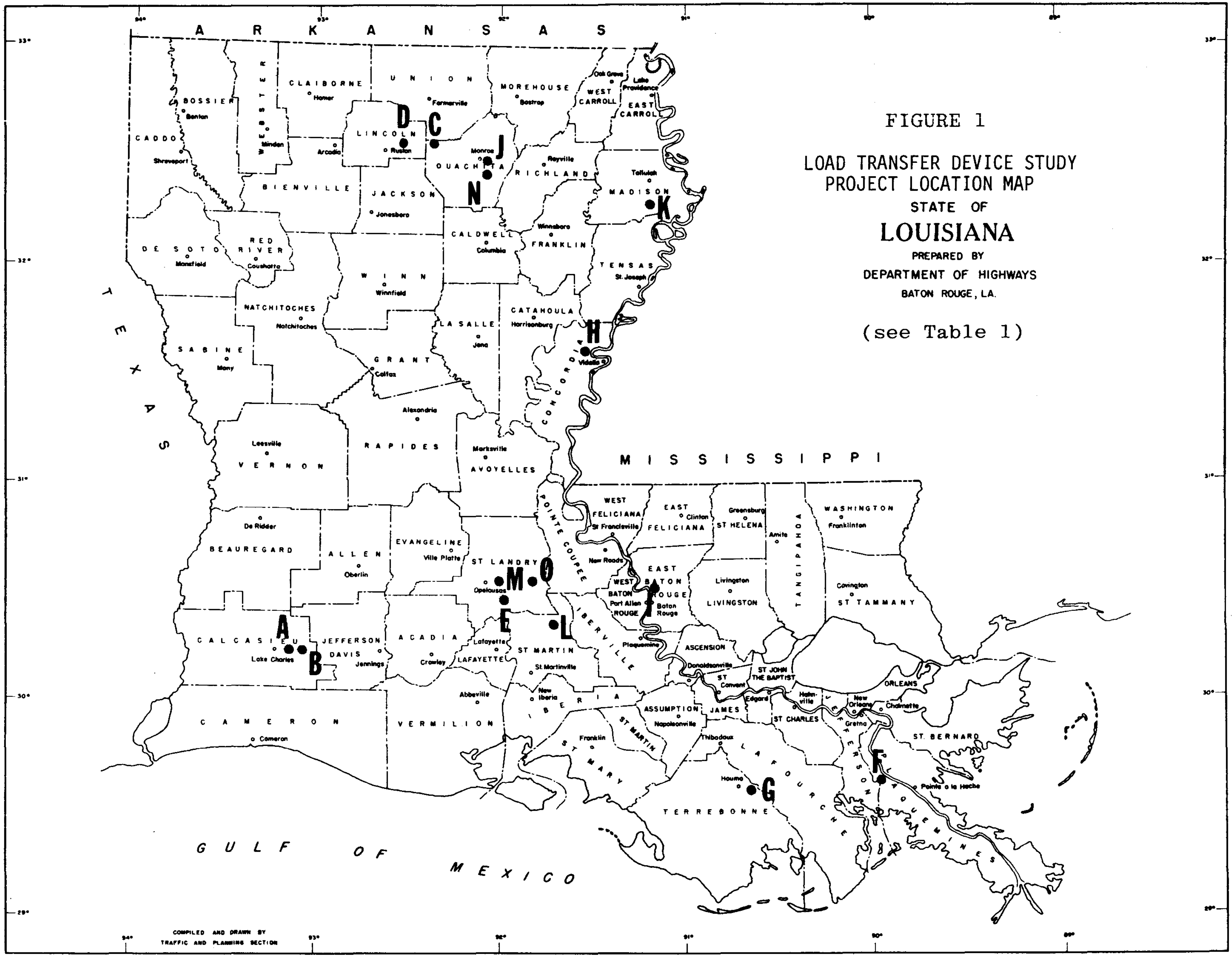


FIGURE 1

LOAD TRANSFER DEVICE STUDY
PROJECT LOCATION MAP
STATE OF
LOUISIANA
PREPARED BY
DEPARTMENT OF HIGHWAYS
BATON ROUGE, LA.

(see Table 1)

TABLE 1

PROJECT LOCATION AND PAVEMENT CHARACTERISTICS

Project I.D. No.	Map Location	State Project Number	State Route	Parish	PCC Thickness Inches	Base*	Subbase
			58.5 foot slab length				
1	A	450-02-26	I-10	Calcasieu	10	6" Sd. Sh.	6" Lime Treated
2	A	450-02-25	I-10	Calcasieu	10	6" Sd. Sh.	6" Lime Treated
3	A	450-02-26	I-10	Calcasieu	10	6" Sd. Sh.	6" Lime Treated
4	A	450-02-25	I-10	Calcasieu	10	6" Sd. Sh.	6" Lime Treated
5	B	450-30-07	I-210	Calcasieu	10	1" S.A./6" S.C.	6" Select
6	B	450-30-06	I-210	Calcasieu	10	1" S.A./6" S.C.	6" Lime Treated
7	B	450-30-07	I-210	Calcasieu	10	1" S.A./6" S.C.	6" Select
8	B	450-30-06	I-210	Calcasieu	10	1" S.A./6" S.C.	6" Lime Treated
9	C	740-00-25	I-20	Ouachita	10	2" Sand/6" S.C.	6" Select
10	C	740-00-26	I-20	Ouachita	10	2" Sand/6" S.C.	6" Select
11	C	740-00-25	I-20	Ouachita	10	2" Sand/6" S.C.	6" Select
12	C	740-00-26	I-20	Ouachita	10	2" Sand/6" S.C.	6" Select
13	D	740-00-21	I-20	Lincoln	10	6" S.C.	6" Select
14	D	740-00-22	I-20	Lincoln	10	1" Sand/6" S.C.	6" Select
15	D	740-00-21	I-20	Lincoln	10	6" S.C.	6" Select
16	D	740-00-22	I-20	Lincoln	10	1" Sand/6" S.C.	6" Select
17	E	424-01-01	US-167	St. Landry	10	1" Sand/6" S.C.	6" Select
18	E	424-02-12	US-167	St. Landry	10	1 1/2"S.A./6" S.C.	6" Select
19	E	424-01-01	US-167	St. Landry	10	1" Sand/6" S.C.	6" Select
20	E	424-02-12	US-167	St. Landry	10	1 1/2"S.A./6" S.C.	6" Select

* Sd. Sh. = Sand Shell
* S.A. = Sand Asphalt
* S.C. = Soil Cement

TABLE 1 (CONTINUED)

PROJECT LOCATION AND PAVEMENT CHARACTERISTICS

Project I.D. No.	Map Location	State Project Number	State Route	Parish	PCC Thickness Inches	Base*	Subbase
				30 foot slab length			
21	F	62-02-13	LA-23	Plaquemines	9-6-9	Embankment	
22	G	248-03-04	LA-55	Terrebonne	9-6-9	Embankment	
				20 foot slab length			
23	H	26-02-19	US-65	Concordia	9	6" S.C.	6" Select
24	H	26-02-23	US-65	Concordia	9	6" S.C.	6" Select
25	I	252-01-03	US-61	East Baton Rouge	9	3 1/2" Sand	Silty Clay
26	J	15-31-03	US-165	Ouachita	9	6" S.C.	6" Select
27	K	20-06-17	US- 65	Madison	9	6" Sand	Heavy Clay
28	L	450-06-01	I-10	St. Martin	10	4" Asphalt	6" Lime Treated
29	M	12-13-34	US-190	St. Landry	9	6" Sand	12" Select
30	N	15-31-02	US-165	Ouachita	9	6" S.C.	6" Select
31	O	12-13-35	US-190	St. Landry	9	1" S.A./6"Sd. Sh.	Embankment

* Sd. Sh. = Sand Shell
S.A. = Sand Asphalt
S.C. = Soil Cement

METHODOLOGY AND DATA ANALYSIS

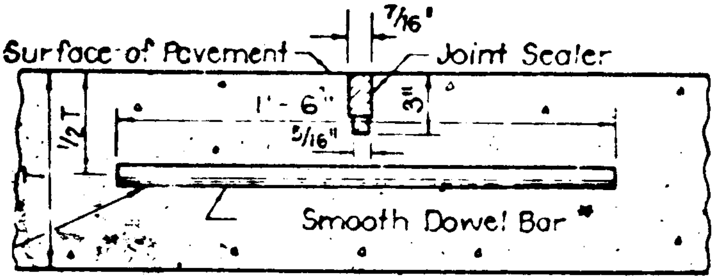
Field engineers from each of Louisiana's nine highway districts were solicited to determine which type of load transfer device had been used on state highway projects. (Starlugs and dowel bars are pictured in Figures 2-5.)

Projects with dowel bars and starlugs were paired together for evaluation. In the selection of projects for evaluation an attempt was made to pair adjoining highway projects. Projects which shared the same geographical location were chosen where adjoining projects were not available.

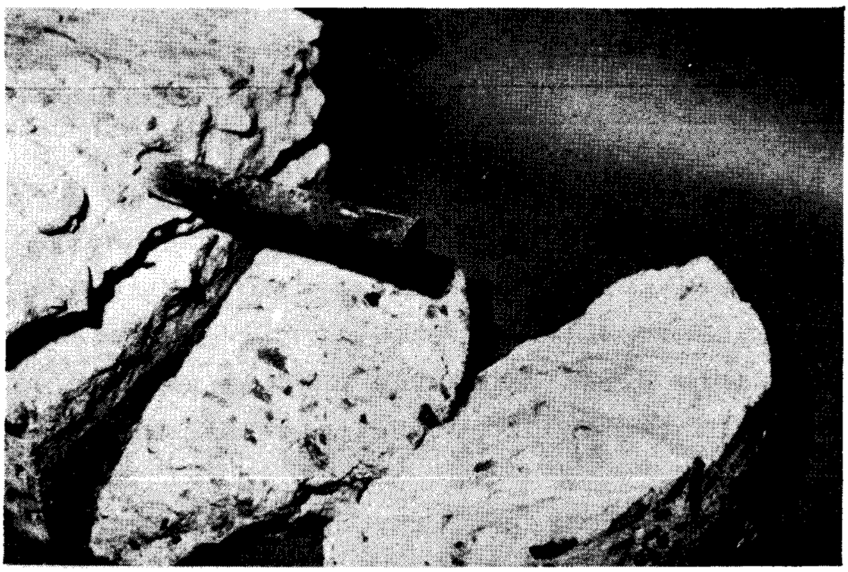
Projects having four lanes were paired according to the direction of traffic in each roadway. This made possible a comparison of lanes with similar loading and eliminated the factor of directional distribution. Six lots of 20 slabs each were selected at random from the beginning, middle, and last sections of each paired project--three lots in the inside lane and three lots in the outside lane. Figure 6 is a layout of the sampling procedure.

The 31 paired projects generated in excess of 3500 data points. All field data were coded as punched cards for analysis. The individual data points were reduced to average data for each lot which was subsequently converted to single observations for each project. Table 2 indicates the overall average for each project and Table 5 in the Appendix indicates average data for each lot.

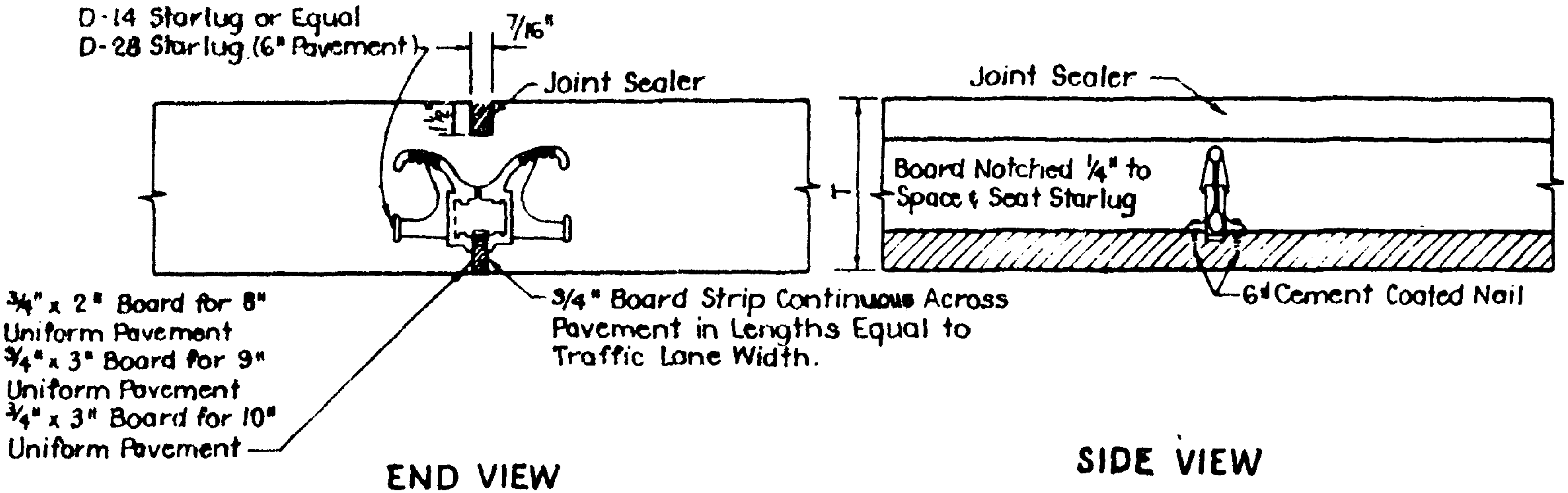
In these tables, projects 1 through 20 represent data for 58.5-foot (17.8-m) joint spacing. Projects 21 and 22 represent 30-foot (9.1-m) slab lengths; and the remaining projects, 20-foot (6.1-m) joint spacing. The pairing of projects, which appears in sequence, is according to like parameters. Thus, projects 1 and 2 are paired according to their traffic and pavement section parameters with the type of load transfer device as the primary



Dowel Bar in Transverse Joint
FIGURE 2



Dowel Bar in Core
FIGURE 3



Starlug in Transverse Joint
FIGURE 4

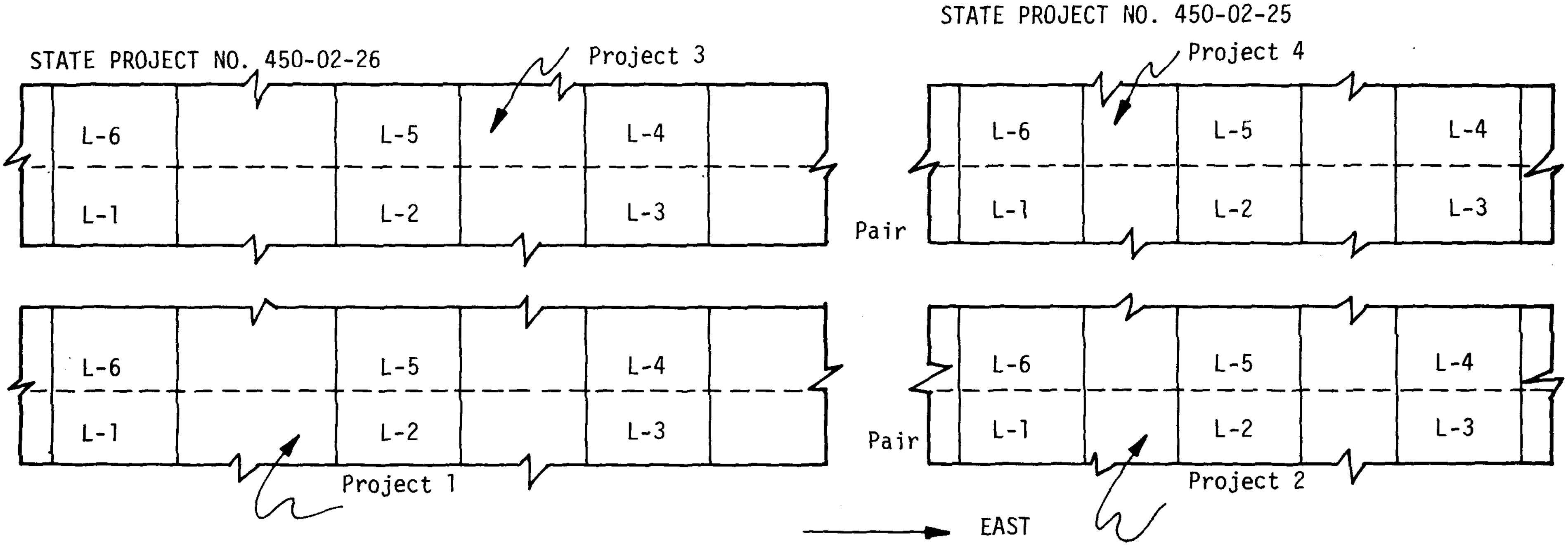
Starlugs on Redwood Board

FIGURE 5

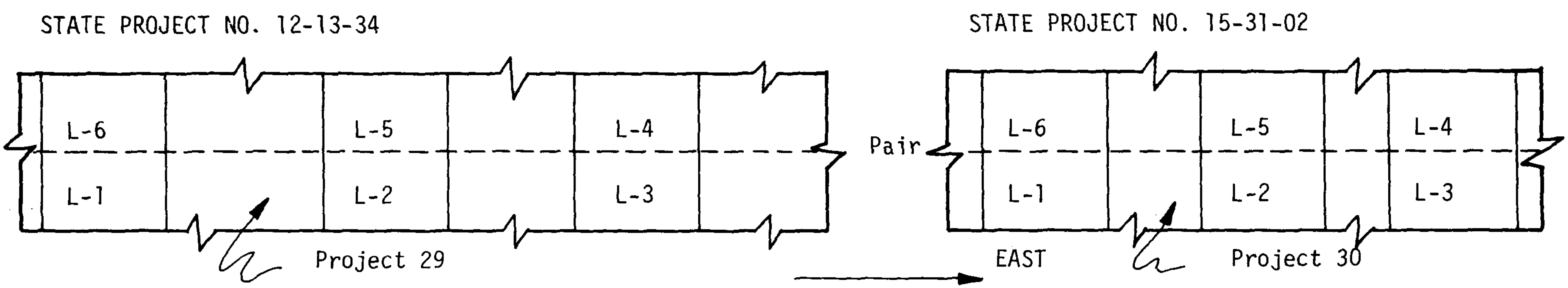
FIGURE NO. 6

PROJECT PAIRING (TYPICAL)

4 Lane Highway



2 Lane Highway



NOTE: L = lot consisting of 21 transverse contraction joints.

TABLE 2

LEAD TRANSFER EVALUATION BY PROJECT

PROJ	LOCT	JTW	AIRT	SRFT	LDIF	HDIF	AVGDIF	SNS1	SNS2	LSCI	HSCI	AVGSCI	T1CRK	T2CRK	T3CRK	T4CRK	T5CRK
(SEE NOTE BELOW FOR EXPLANATION OF COLUMN HEADINGS)																	
1	CB	.55	75	69	.001	.016	.005	0.81	0.64	.01	0.67	0.17	2737	0	16	0	5
2	SL	.55	86	65	.001	.025	.010	0.82	0.49	.00	0.96	0.33	631	1	2	14	10
3	DB	.53	74	65	.000	.022	.003	0.65	0.48	.00	0.51	0.17	531	0	25	18	18
4	SL	.50	82	81	.002	.023	.009	0.65	0.46	.01	0.53	0.19	653	11	6	0	82
5	CB	.54	74	74	.001	.023	.005	0.90	0.66	.06	0.77	0.24	111	0	0	0	2
6	SL	.53	86	67	.001	.054	.008	0.64	0.51	.01	0.24	0.13	1616	5	1	0	1
7	DB	.64	69	66	.000	.023	.006	0.82	0.67	.05	0.30	0.15	128	2	8	0	0
8	SL	.52	70	67	.000	.019	.004	0.77	0.47	.07	0.79	0.30	2144	20	5	0	11
9	CB	.59	75	73	.000	.015	.005	0.60	0.45	.00	0.38	0.15	45	21	81	0	264
10	SL	.49	86	102	.002	.058	.011	0.57	0.48	.01	0.57	0.09	150	48	94	0	246
11	DB	.61	79	95	.000	.020	.006	0.58	0.48	.02	0.51	0.11	99	44	170	0	172
12	SL	.53	79	84	.001	.034	.011	0.62	0.45	.00	0.94	0.17	268	33	171	0	508
13	DB	.58	82	96	.002	.041	.008	0.51	0.39	.05	0.38	0.12	237	65	97	0	68
14	SL	.69	83	89	.000	.024	.007	0.60	0.41	.00	0.56	0.19	284	65	235	0	354
15	DB	.56	67	99	.001	.021	.007	0.56	0.40	.04	0.86	0.16	62	50	94	0	48
16	SL	.66	89	102	.000	.048	.006	0.56	0.40	.00	0.83	0.16	394	32	62	0	286
17	DB	.63	57	58	.000	.023	.006	0.61	0.51	.01	0.60	0.10	353	12	78	0	502
18	SL	.66	62	68	.003	.023	.010	0.78	0.60	.01	0.67	0.18	300	18	214	0	61
19	DB	.68	59	67	.001	.017	.007	0.69	0.53	.01	0.53	0.15	597	17	24	0	379
20	SL	.56	65	68	.002	.021	.010	0.71	0.56	.01	0.49	0.15	95	11	111	0	14
21	DB	.62	70	77	.001	.020	.004	1.40	1.23	.02	0.87	0.17	0	10	403	0	399
22	SL	.48	61	69	.002	.041	.015	2.93	1.43	.16	2.80	1.50	3461	89	0	0	483
23	DB	.41	54	58	.000	.007	.003	1.26	0.74	.31	1.00	0.52	0	0	123	0	9
24	SL	.58	46	55	.001	.016	.005	1.24	0.66	.27	1.37	0.56	0	9	345	0	132
25	CB	.39	82	105	.000	.012	.004	0.90	0.66	.00	0.10	0.04	0	2	147	0	0
26	SL	.52	97	135	.000	.014	.005	0.65	0.61	.00	0.09	0.04	0	0	158	0	22
27	DB	.45	91	105	.000	.010	.002	0.77	0.75	.01	0.06	0.02	53	0	24	0	0
28	SL	.47	90	110	.001	.016	.004	0.49	0.46	.01	0.12	0.03	0	2	0	0	0

TABLE 2 (CONTINUED)

LOAD TRANSFER EVALUATION BY PROJECT

PROJ	LODT	JTW	AIRT	SRFT	LDIF	HDIF	AVGDIF	SNS1	SNS2	LSCI	HSCI	AVGSCI	T1CRK	T2CRK	T3CRK	T4CRK	T5CRK
29	DB	.41	89	118	.001	.024	.006	.71	.66	.02	.10	.05	0	0	57	0	2
30	SL	.42	90	119	.001	.014	.005	.78	.74	.00	.51	.04	0	9	31	0	244
31	DB	.44	86	109	.000	.011	.004	.86	.82	.00	.24	.04	0	4	0	0	4

N=31

NOTE: PROJ - PROJECT NUMBER
LOT - LOT NUMBER
LODT - LOAD TRANSFER DEVICE
DB - DOWEL BAR
SL - STAR LUG
JTW - JOINT WIDTH (IN)
AIRT - AIR TEMPERATURE (F)
SRFT - SURFACE TEMPERATURE (F)
LDIF - MINIMUM FAULTING (FT)
HDIF - MAXIMUM FAULTING (FT)
DIF - FAULTING (FT)
SNS1 - SENSOR 1 (MILLI-INCH)
SNS2 - SENSOR 2 (MILLI-INCH)
LSCI - MINIMUM SCI (MILLI-INCH)
HSCI - MAXIMUM SCI (MILLI-INCH)
SCI - SURFACE CURVATURE INDEX (MILLI-INCH)
T1CRK - TRANSVERSE CRACKING (FT/LANE-MILE)
T2CRK - CORNER CRACKING (FT/LANE-MILE)
T3CRK - PERPENDICULAR JOINT CRACKING (FT/LANE-MILE)
T4CRK - LONGITUDINAL CRACKING (FT/LANE-MILE)
T5CRK - PATCHING AND/OR CORNER BREAKOUT (SQ FT/LANE-MILE)

independent variable and faulting, load transfer capability, joint width and various types of pavement deterioration as the dependent variables. Such pairing, however, was not possible for the projects with 20-foot (6.1-m) joint spacings.

The tables show the range of variation for faulting and deflection parameters along with the average for each project. Table 3 represents a summary of average data for the two load transfer devices according to joint spacing. The analysis is based on raw averages. The summary table was prepared from data in Table 2 and Table 5 in the Appendix. Figures 7 to 9 represent data from Tabel 3 in graphical form.

To verify the type of load transfer device in each project, several transverse contraction joints were cored. Field data included measurement of joint widths, slab faulting, cracking and patching, slab deflections, and load transfer capability across joints, as well as pavement and ambient temperatures. The widths of transverse contaction joints were measured with calipers, making two readings per joint. Taking paired elevation shots at 4-foot (1.2-m) intervals, research personnel used a surveyors level to measure slab faulting.

All occurrences of cracking and patching were mapped in the field and have been presented as feet or square feet per lane-mile. To permit a relative comparison of deterioration on pavements with three different slab lengths, the average cracking in each project (six lots) was projected to one mile of roadway, one lane wide. The five types of surface deterioration measured may be seen in figure 10 through 16 and include the following:

Type 1-transverse slab cracking
Type 2-slab corner cracking
Type 3-joint cracking (perpendicular to joint)
Type 4-longitudinal slab cracking
Type 5-patching and/or corner breakout

TABLE 3

EVALUATION OF LOAD TRANSFER DEVICES (58.5 FT. SLABS)

LDDT	JTW	AIRT	SRFT	LDIF	HDIF	DIF	SNS1	SNS2	LSCI	HSCI	SCI	T1CRK	T2CRK	T3CRK	T4CRK	T5CRK
DB	.59	74	76	.001	.022	.006	.67	.52	.03	.55	.15	494	21	59	2	146
SL	.57	75	79	.001	.037	.009	.67	.48	.01	.65	.19	654	24	90	1	157

N=2

EVALUATION OF LOAD TRANSFER DEVICES (30 FT. SLABS)

LDDT	JTW	AIRT	SRFT	LDIF	HDIF	DIF	SNS1	SNS2	LSCI	HSCI	SCI	T1CRK	T2CRK	T3CRK	T4CRK	T5CRK
DB	.62	70	77	.001	.020	.004	1.40	1.23	.02	0.87	0.17	0	10	403	0	399
SL	.48	61	69	.002	.041	.015	2.93	1.43	.18	2.80	1.50	3461	89	0	0	483

N=2

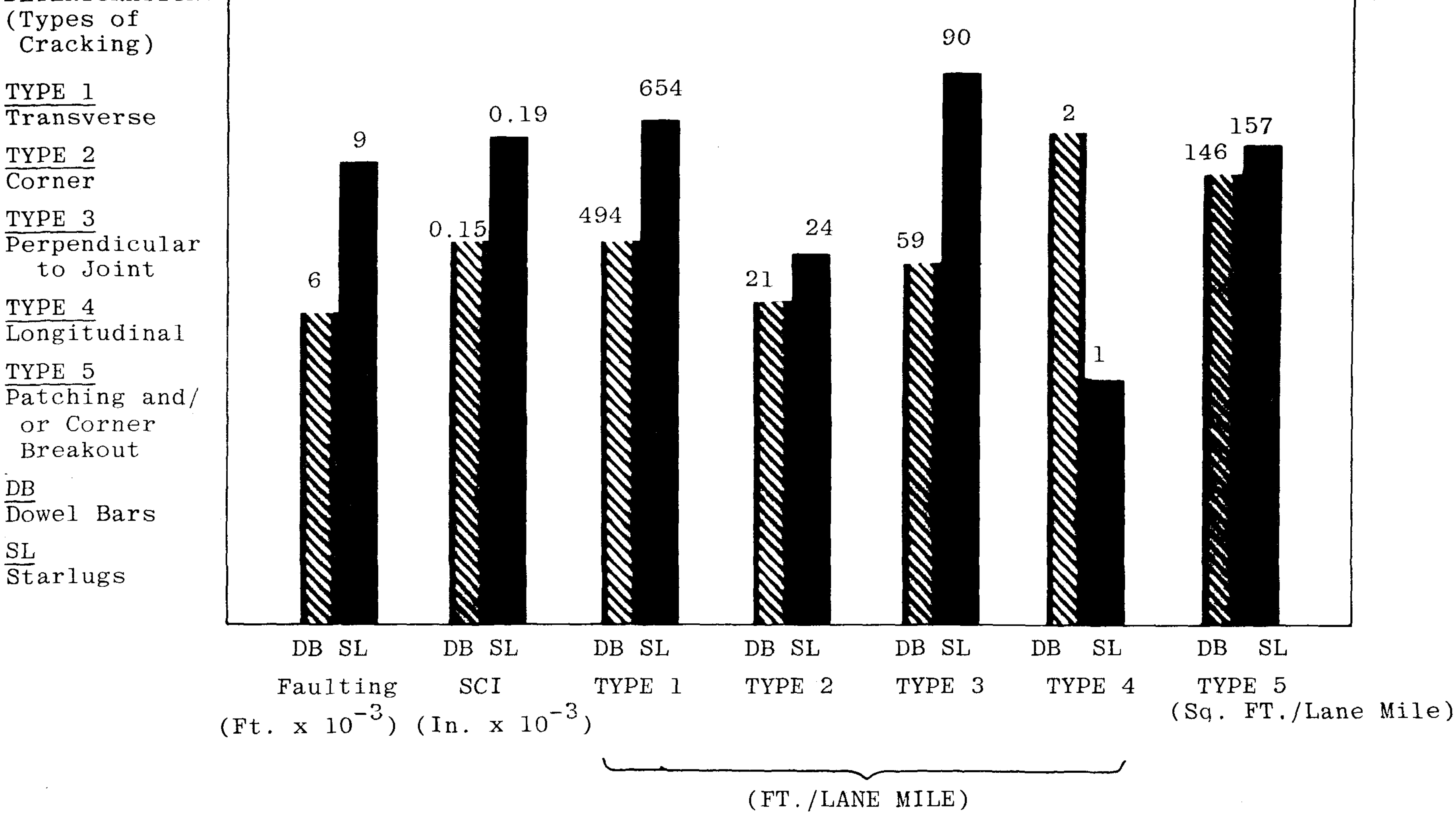
EVALUATION OF LOAD TRANSFER DEVICES (20 FT. SLABS)

LDDT	JTW	AIRT	SRFT	LDIF	HDIF	DIF	SNS1	SNS2	LSCI	HSCI	SCI	T1CRK	T2CRK	T3CRK	T4CRK	T5CRK
DB	.42	80	99	.000	.013	.004	.90	.77	.07	.30	.13	11	1	70	0	3
SL	.50	81	104	.001	.015	.005	.79	.62	.07	.52	.17	0	5	134	0	100

N=2

NOTE: PROJ - PROJECT NUMBER
LOT - LOT NUMBER
LODT - LOAD TRANSFER DEVICE
DB - DOWEL BAR
SL - STAR LUG
JTW - JOINT WIDTH (IN)
AIRT - AIR TEMPERATURE (F)
SRFT - SURFACE TEMPERATURE (F)
LDIF - MINIMUM FAULTING (FT)
HDIF - MAXIMUM FAULTING (FT)
DIF - FAULTING (FT)
SNS1 - SENSOR 1 (MILLI-INCH)
SNS2 - SENSOR 2 (MILLI-INCH)
LSCI - MINIMUM SCI (MILLI-INCH)
HSCI - MAXIMUM SCI (MILLI-INCH)
SCI - SURFACE CURVATURE INDEX (MILLI-INCH)
T1CRK - TRANSVERSE CRACKING (FT/LANE-MILE)
T2CRK - CORNER CRACKING (FT/LANE-MILE)
T3CRK - PERPENDICULAR JOINT CRACKING (FT/LANE-MILE)
T4CRK - LONGITUDINAL CRACKING (FT/LANE-MILE)
T5CRK - PATCHING AND/OR CORNER BREAKOUT (SQ FT/LANE-MILE)

FIGURE 7
COMPARISON OF STARLUGS AND DOWEL BARS
58.5 FOOT JOINT SPACING



PAVEMENT DETERIORATION: (Type of Cracking)

TYPE 1
Transverse

TYPE 2
Corner

TYPE 3
Perpendicular to Joint

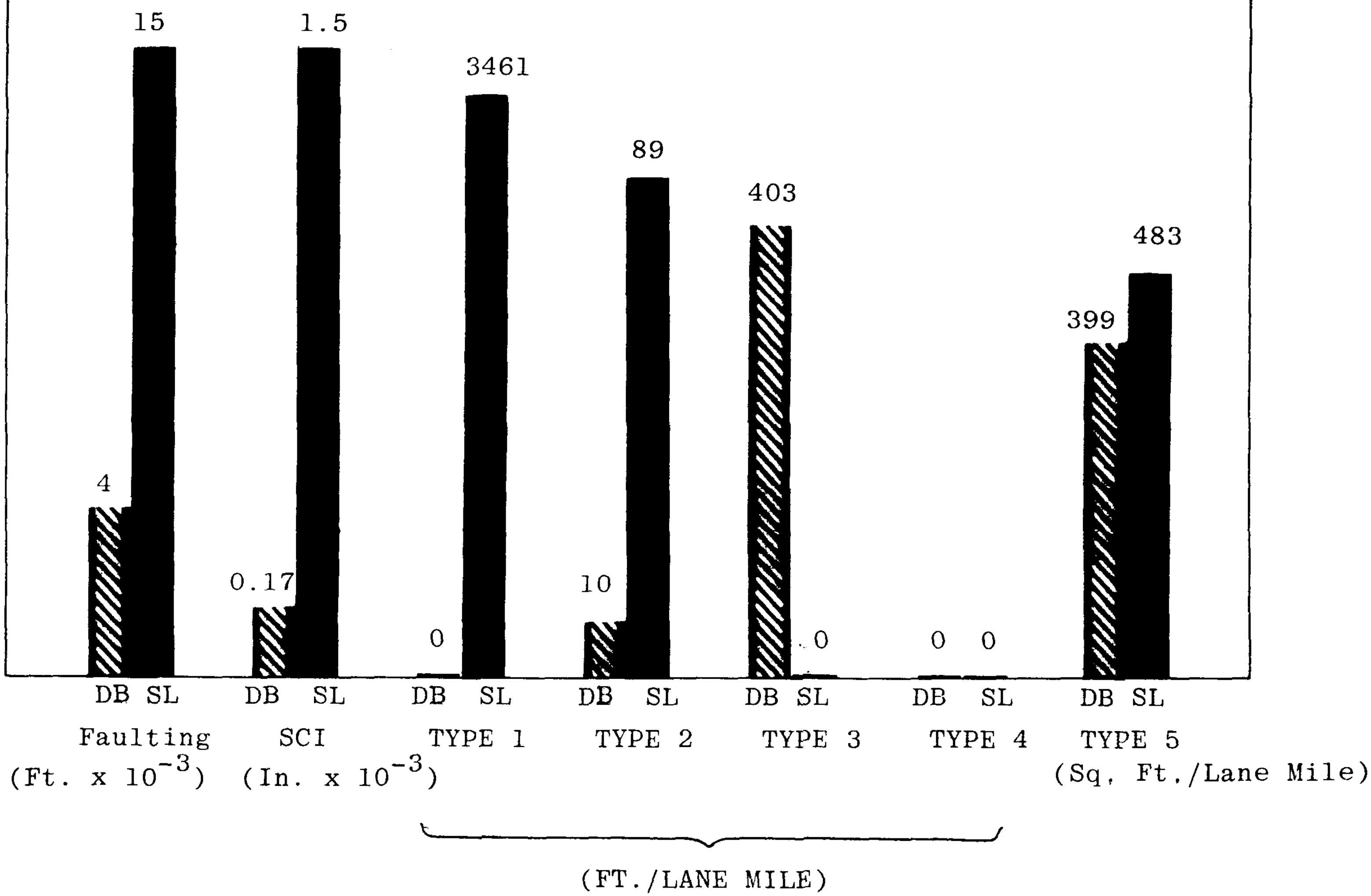
TYPE 4
Longitudinal

TYPE 5
Patching and/ or Corner Breakout

DB
Dowel Bars

SL
Starlugs

FIGURE 8
COMPARISON OF STARLUGS AND DOWEL BARS
30 FOOT JOINT SPACING



PAVEMENT DETERIORATION: (Types of Cracking)

TYPE 1
Transverse

TYPE 2
Corner

TYPE 3
Perpendicular to Joint

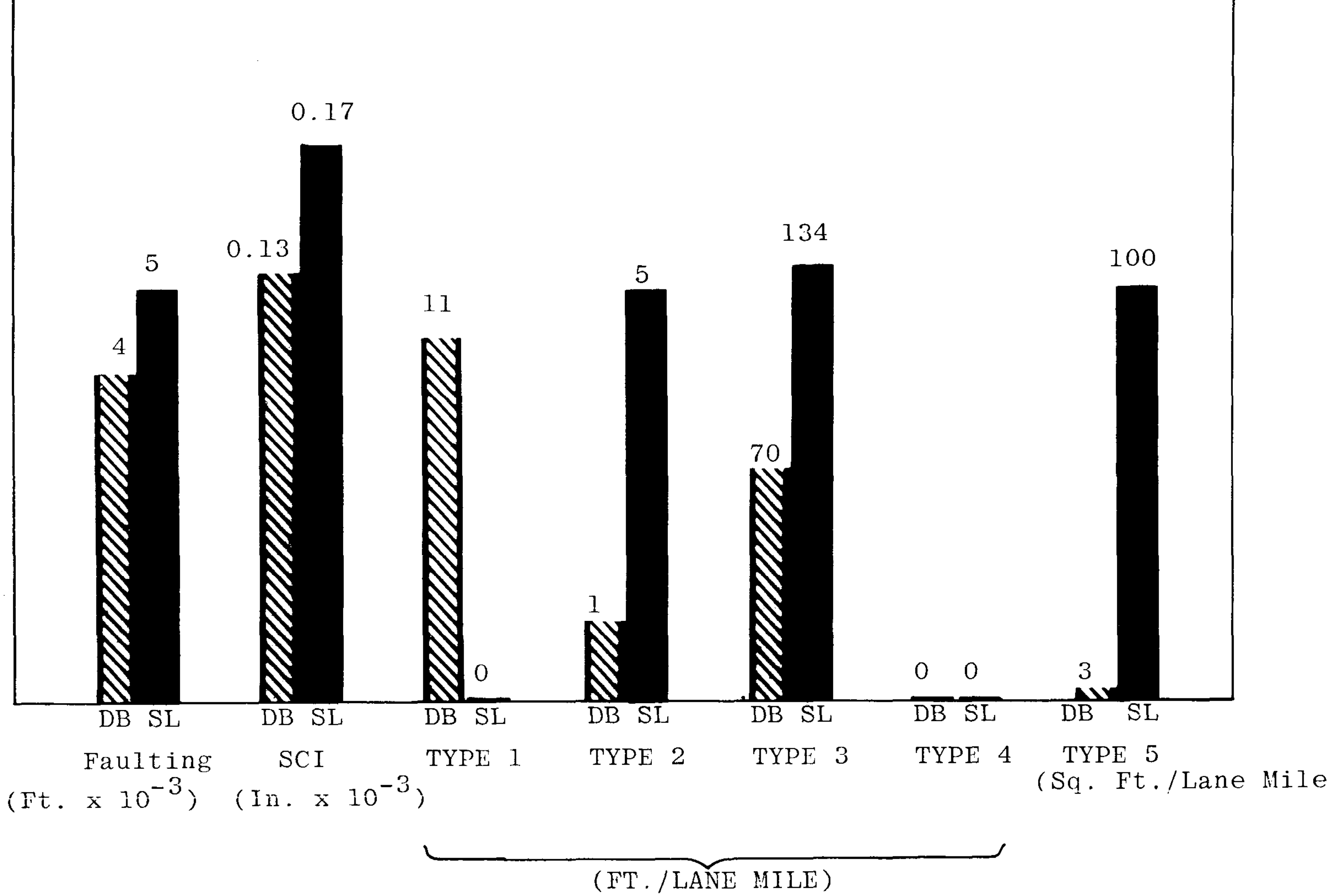
TYPE 4
Longitudinal

TYPE 5
Patching and/or Corner Breakout

DB
Dowel Bars

SL
Starlugs

FIGURE 9
COMPARISON OF STARLUGS AND DOWEL BARS
20 FOOT JOINT SPACING



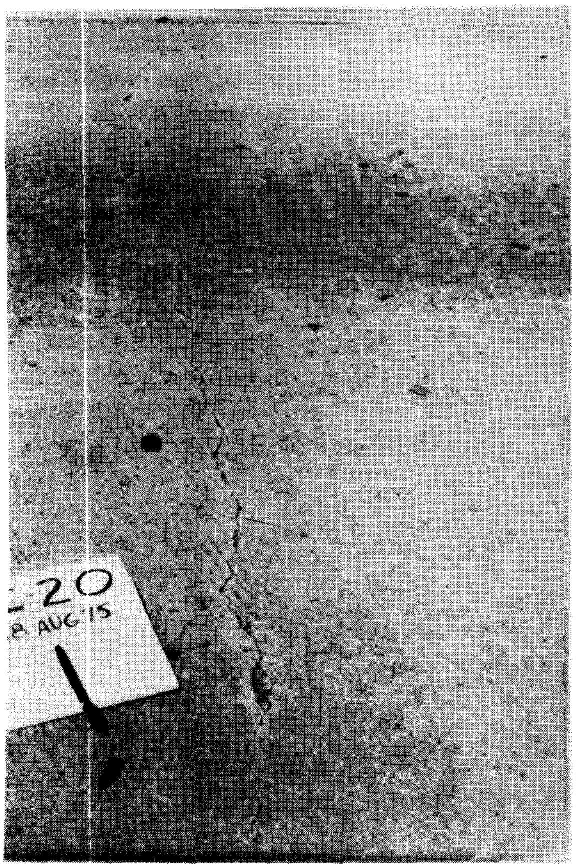


FIGURE 10
Transverse Cracking

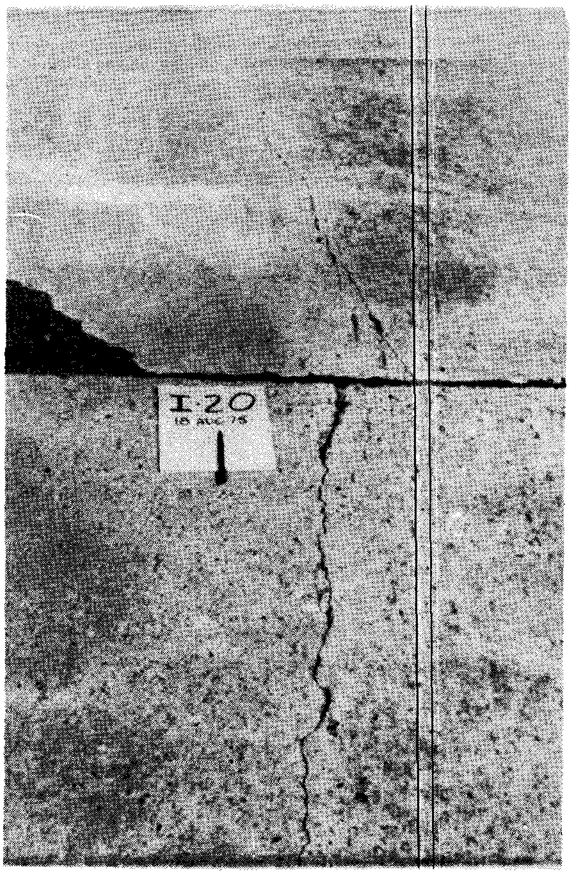


FIGURE 11
Perpendicular Joint Cracking

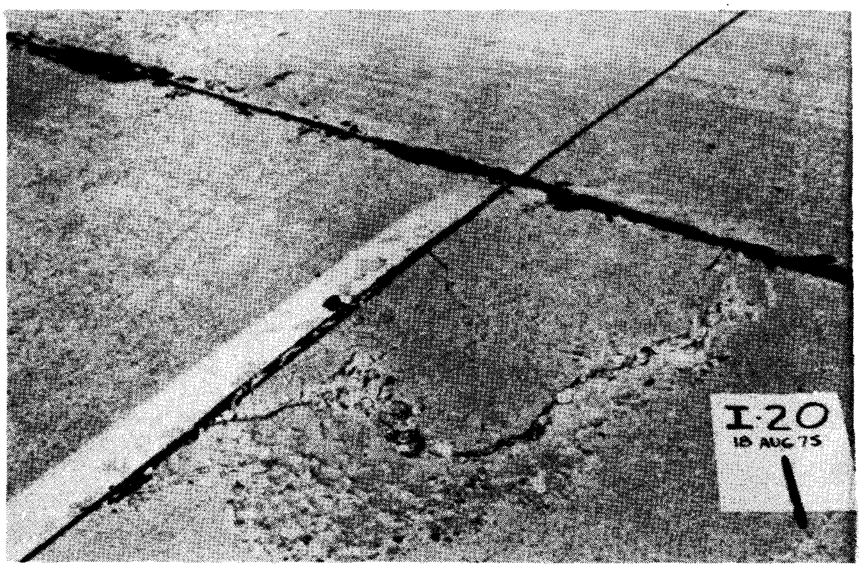


FIGURE 12
Corner Cracking

FIGURE 13
Corner Breakout

FIGURE 14
Asphalt Patch

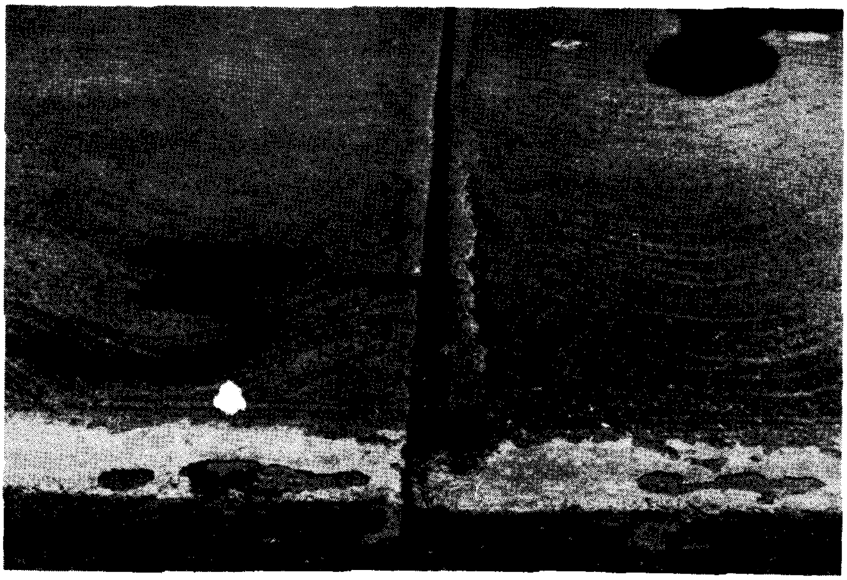


FIGURE 15
Slab Faulting

FIGURE 16
Slab Faulting

The Dynamic Deflection Determination System (Dynaflect) was used to measure slab deflection and load transfer capability across joints. As can be seen in Figure 17, it is a trailer-mounted device which induces a dynamic load on the pavement and measures the resulting slab deflections by use of geophones (usually five) spaced under the trailer at approximately one-foot (39.5-cm) intervals from the application of the load. The pavement is subjected to a 1000-pound (454-kg) dynamic load at a frequency of eight cycles per second, which is produced by the counter-rotation of two unbalanced flywheels. The generated cyclic force is transmitted vertically to the pavement through two steel wheels spaced 20 inches (50.8-cm) center-to-center. Any horizontal reactions will cancel each other due to the opposing rotations. The dynamic force varies in sine wave fashion from 500 pounds (227 kg) upward to 500 pounds (227 kg) downward during each rotation. The entire force transmitted to the pavement, however, consists of the weight of the trailer (about 1600 pounds or 726 kg) and the dynamic force which alternately adds to and subtracts from the static weight. Thus, the dynamic force during each rotation of the flywheels at the proper speed varies from 1100 to 2100 pounds (499 to 953 kg). The deflection measurements induced by this system are expressed in terms of milli-inches of deflection (thousandths of an inch).

To determine load transfer capability, the Dynaflect was positioned so that sensors I and II fell on each side of a transverse contraction joint. The Corps of Engineers used this method of determining load transfer as far back as 1967(1).* The numerical difference in deflection readings on each side of the joint has been referred to as the "step up", or vertical displacement between slabs. The difference between the reading of sensors I and II

*Underlined number in parentheses refer to "References".

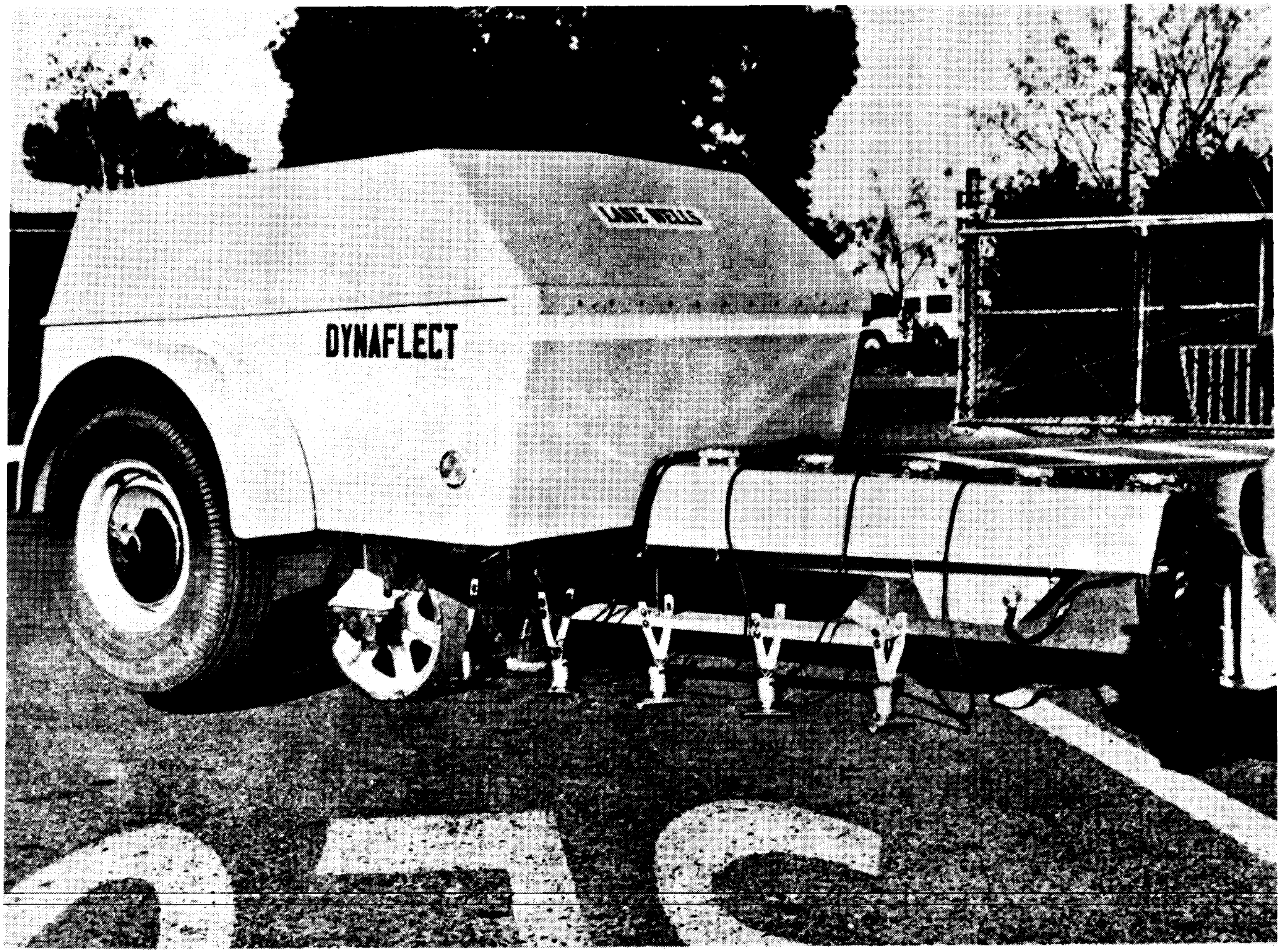


FIGURE 17
Dynaflect Deflection Determination System

has also been referred to as the Surface Curvature Index or S.C.I. (2). This value gives an indication of the load carrying ability of the upper pavement layers. Load transfer capability values in tables 2 and 3 are identified as average S.C.I. These "step ups," or S.C.I. values, provide a means of comparing the relative load transfer capability between adjacent pavement slabs. An S.C.I. value of 0.00 milli-inches would indicate 100 percent of the traffic load being transmitted between slabs; thus, the higher the S.C.I. value, the less load transfer provided by the devices. Load transfer can also be dependent on interlock of exposed aggregate between pavement slabs. The load transfer provided by aggregate interlock increases as pavement temperatures increase and the joints close. This variation with temperature reaffirms the necessity of pairing projects and evaluating them as pairs.

The following guidelines indicate the relative levels of load transfer capability as determined by the Dynaflect:

Surface Curvature Index	Load Transfer Capability
0.00 - 0.15	Good
0.16 - 0.33	Fair
0.34 or larger	Poor

DISCUSSION OF RESULTS

Results of field tests and performance of projects with the various joint spacings are discussed from two aspects--measured load transfer capability, and general pavement deterioration including slab faulting and cracking. It is not the intent of this study to determine which modes of pavement deterioration are a direct result of frozen, locked, or misaligned load transfer devices. The data presented here in many cases does, however, indicate definite trends in the overall performance of paired projects.

58.5 Foot (17.9-m) Joint Spacing, Projects (1-20)

Projects 1-20 are discussed as a group because of the pairing procedures described earlier. The ability to transfer traffic loads from one slab to the next is naturally the primary function of all load transfer devices. Field measurement of transverse contraction joints with the Dynaflect device indicated that projects built with starlugs had 27 percent less load transfer capability than projects built with dowel bars.

From a pavement deterioration standpoint, starlug projects contained, on the average, 37 percent more transverse cracking, 19 percent more corner cracking, 37 percent more perpendicular cracking at joints, and 12 percent more corner breakout and patching.

Projects with the 58.5-foot (17.8-m) joint spacing exhibited only minor slab faulting and almost no longitudinal cracking.

30-Foot (9.1-m) Joint Spacing, Projects (21-22)

The two projects with 30-foot (9.1-m) joint spacings represent the oldest PCC highways evaluated in this study. As indicated in Table 4, the dowel bar project was built in 1950 and has accumulated an 18- kip

TABLE 4

TRAFFIC DATA AND TYPE OF LOAD TRANSFER DEVICE

Project I.D. No.	Completion Date	1974 ADT	1974 ADL[1]	18 kip Load Since Construction	Load Transfer Device
		58.5 foot slab length			
1	7/15/64	15,340	964.93	3,002,350	Dowel Bar
2	6/19/64	12,500	786.28	2,797,600	Starlug
3	7/15/64	15,340	964.93	3,002,350	Dowel Bar
4	6/19/64	12,500	786.28	2,797,600	Starlug
5	11/12/64	8,300	30.40	101,150	Dowel Bar
6	9/25/64	9,150	33.51	118,280	Starlug
7	11/12/64	8,300	30.40	101,150	Dowel Bar
8	9/25/64	9,150	33.51	118,280	Starlug
9	9/21/61	10,190	732.83	2,644,200	Dowel Bar
10	12/20/60	13,270	954.33	2,857,750	Starlug
11	9/21/61	10,190	732.83	2,644,200	Dowel Bar
12	12/20/60	13,270	954.33	2,852,750	Starlug
13	2/28/61	10,500	907.66	3,117,250	Dowel Bar
14	6/1/60	10,120	727.80	2,641,000	Starlug
15	2/28/61	10,500	907.66	3,117,250	Dowel Bar
16	6/1/60	10,120	727.80	2,641,000	Starlug
17	12/20/63	8,050	434.76	2,131,310	Dowel Bar
18	9/28/64	12,260	662.13	2,559,950	Starlug
19	12/20/63	8,050	434.76	2,131,310	Dowel Bar
20	9/28/64	12,260	662.13	2,559,950	Starlug
		30 foot slab length			
21	12/22/50	4,860	129.51	821,100	Dowel Bar
22	3/19/53	4,550	79.39	373,650	Starlug
		20 foot slab length			
23	9/5/63	12,130	610.93	2,047,380	Dowel Bar
24	7/22/66	13,990	704.61	1,657,450	Starlug
25	7/26/61	5,440	470.31	1,746,350	Dowel Bar
26	9/16/65	15,470	1111.66	2,925,620	Starlug
27	4/9/63	1,660	130.28	389,720	Dowel Bar
28	3/7/73	11,580	532.15	29,980	Starlug
29	8/3/61	6,020	358.96	2,697,570	Dowel Bar
30	9/16/63	3,280	262.61	938,870	Starlug
31	9/30/64	4,500	268.43	1,959,950	Dowel Bar

1 ADL = Average Daily Load in 18-kip Axle Loads

equivalent axle load of 821,100. The starlug project was constructed in 1953 and has carried less than half that load. Both projects were built with PCC pavement over a nonstabilized base consisting of embankment material.

Average joint width measurements indicate narrower transverse joints for the starlug project than for the dowel bar project. The reason for this difference can be observed in Table 3 -- the starlug project contained 3461 feet (1055-m) per lane-mile of transverse cracking, while the dowel bar project contained none.

Dynaflect readings clearly indicated that the starlugs had completely failed to transfer load, while the dowel bars were doing an excellent job after 23 years of service.

The starlug project also exhibited greater slab faulting, 21 percent more corner breakout and patching, and 9 times more corner cracking. However, the dowel bar project contained some very fine, hairline perpendicular joint cracks.

<u>20-Foot (6.1-m) Joint Spacing, Projects (23-31)</u>

Projects 23-31 are discussed firstly as a group and secondly as individual pairs. It is felt that a discussion of individual pairs will facilitiate the comparison of highway projects paired randomly.

Projects built with starlugs had, on the average, 31 percent less load transfer capability than projects built with dowel bars. The starlug projects contained slightly more corner cracking while the dowel bar projects contained slightly more transverse cracking. Neither group exhibited longitudinal slab cracking. The starlug projects did, however, contain roughly twice as much perpendicular joint cracking and 33 times more corner breakout and patching.

Projects (23, 24)

It should be noted for purposes of comparison that the dowel bar project in this pair is approximately three years older and has carried 24 percent more total load than the starlug project. As shown in Table 1, pavement characteristics and geographical location are identical.

The starlug project exhibited slightly less load transfer capability and slightly more faulting than did the dowel bar project. It also contained considerably more corner cracking, perpendicular joint cracking, and patching.

Projects (25,26)

Although the dowel bar project in this pair was four years older, the starlug project had a larger ADT. A more important consideration, however, is the fact that the project built with starlugs had a six-inch (15.2-cm) soil-cement base, while the dowel bar project had only 3-1/2 inches (8.9-cm) of sand.

Despite the structural superiority provided by the stablized base, the starlugs exhibited a load transfer capability no greater than that of the dowel bars.

In addition, the project built with starlugs contained more faulting perpendicular joint cracking, corner breakout, and patching. The dowel bar project showed only minor signs of corner cracking and contained no area type cracking at all.

Projects (27,28)

As can be seen in Table 4, this dowel bar project is 10 years older and has carried 33 percent more total load. Structurally, it consists of a nine-inch (22.9-cm) PCC surface, a six-inch

(15.2-cm) sand base over untreated heavy clay subgrade material. On the other hand, the starlug project consists of a 10-inch (25.4-cm) PCC surface, a four-inch (10.2-cm) asphalt base, and a six-inch (15.2-cm) lime treated subbase. Again, despite the comparative advantages, the starlug project exhibited more faulting and less load transfer capability.

Neither project contained longitudinal cracking, corner breakout, or patching. Although the dowel bar project contained minor transverse and perpendicular joint cracking, its performance was considered very good for a pavement with this age and structural characteristics.

Projects (29,30)

In this pair the dowel bar project was two years older and had carried 2.9 times more total load at the time of testing. Again, a distinction must be made between two types of bases, six-inches (15.2-cm) of soil-cement for the starlugs and six-inches (15.2-cm) of sand for the dowels.

Both projects indicated very good load transfer capability and contained only the slightest amount of slab faulting. The starlug project did, however, contain 99 percent more corner breakout and patching.

Project (31)

Due to the limited number of projects avaiable for evaluation, one dowel bar project could not be paired and is presented here for information only. The project was constructed in 1964 and has carried two million total 18-kip equivalent axle loads. It is comprised of nine inchs (22.9-cm) of PCC, a 1-inch (2.5-cm) layer of sand asphalt, and six-inches (15.2-cm) of sand shell.

As with most of the other projects containing 20-foot (6.1-m) slabs, this project contained only minor slab faulting and exhibited very good load transfer.

Installation of Starlugs and Dowel Bars

Although several methods of installing these devices are currently in use, proper installation is still difficult and sometimes impossible. To insure proper performance the devices must be vertically positioned to a specified depth and correctly spaced in a straight line across the road. After concrete is poured and vibrated, transverse joints must be formed directly over the devices to insure creation of only one plane of weakness. In many cases where joints were not formed over the devices and two planes of weakness were created, spalling between the two "planes" has occurred. Proper alignment and placement of the paper used to form joints is more difficult where starlugs are used, since they are not as easy a target as the 18-inch (45.7-cm) dowel bars. It is believed that the projects evaluated on this study had load transfer devices which were preset prior to the placement of concrete.

Proper orientation of starlugs and dowel bars to preventtilting or turning while concrete is being poured and vibrated is also very critical. The devices may be fixed into redwood boards, wire chairs, or various assemblies prior to placement of concrete. These methods do not always prevent the devices from becoming misaligned or shoved forward. In addition, the chairs, boards, and assemblies create an obstacle for concrete vibrators. Adequate consolidation of concrete around the starlugs and dowel bars is unlikely because vibrators must be raised when approaching the devices. Better consolidation can be obtained by mechanical placement of the devices after the concrete is poured. However, since there are no chairs or assemblies to fix their positions, the starlugs or dowel bars can be stepped on or misaligned due to an equipment malfunction such as a faulty release mechanism. The starlugs evaluated in this study were preset on redwood boards installed prior to the placement of concrete, as determined by cores taken at transverse joints.

Results of Questionnaire

The analysis and evaluation presented in the preceding sections were based on the assumption that the magnitude of the performance parameters measured was due to the differences in the load transfer devices. To determine the concensus with respect to construction problems associated with the installation of starlugs and dowel bars, the Department's construction engineers, experienced in PCC construction, were requested to respond to the questionnaire shown in Figure 18 in the Appendix.

A total of 41 responded. Of these, 19 were used in the final analysis. Of the 22 not considered in the analysis, 7 had had no experience with PCC pavement construction and 15 had experience with either one of the devices on only one occasion. In other words, those that had experience on at least two projects for both the devices were considered in the final evaluation. The results of the questionnaire follow:

Question 1

Approximate number of concrete paving jobs you have been associated with? 334 (total of all 19 responses).

Question 2

Approximate number of these jobs were:

Starlugs	53.3%
Dowel Bars	46.1%

Question 3

What has given you the most trouble?

Starlugs	84.2%
Dowel Bars	10.5%
No Opinion	5.3%

Question 4

What trouble have you encountered with each? For this question most of these had encountered trouble with respect to placement of these devices as follows:

Starlugs	68.4%
Dowel Bars	10.5%
Both	21.1%

Question 5

Which do you prefer to use?

Starlugs	5.3%
Dowel Bars	84.1%
Neither	10.6%

Question 6

Why? The reason for their preference was the ease of placement of these devices.

Starlugs	5.3%
Dowel Bars	84.1%
No Opinion	10.6%

On the basis of the above analysis, it could be inferred that dowel bars are far less susceptible to construction oriented problems as are the corresponding starlugs.

CONCLUSIONS AND RECOMMENDATIONS

The findings of this report indicate the following:

(1) For a given slab length, projects built with dowel bars exhibited less faulting, better load transfer across the joints, and relatively less pavement deterioration than those built with starlugs. On projects with 20-foot (6.1-m) slabs, starlug jobs had 33 times as much corner breakout and patching as those built with dowel bars. This type of deterioration is usually associated with locked joints and/or misaligned load transfer devices. (Table 3 and Figures 7 through 9.)

(2) The perpendicular cracking at transverse contraction joints occurred much more often on starlug jobs than on dowel bar jobs.

(3) On the basis of the analysis of questionnaires sent to construction engineers, it could be inferred that dowel bars are far less susceptible to construction oriented problems than are the corresponding starlugs.

(4) Random coring and visual observations of load transfer devices indicated no major corrosion of either starlugs or dowel bars. This was expected since chemical deicers are not used on pavements in Louisiana. Therefore, use of plastic coated dowel bars is not recommended.

(5) Dowel bars with a diameter larger than one inch (2.5-cm) are not warranted for use in Louisiana. All dowel bar projects evaluated contained one-inch (2.5-cm) diameter bars. Average S.C.I. values for the dowel bar projects with 58.5-foot (17.8-m), 20-foot (6.1-m), and 30-foot

(9.1-m) slab lengths were 0.15, 0.13, and 0.17 milli-inches, respectively. This indicates "good" load transfer capability in the first two categories and "fair" load transfer capability in the 30-foot (9.1-m) category. (It should be noted, however, that the 0.17 milli-inch S.C.I. value is very nearly in the "good" category. In addition, the 30-foot (9.1-m) project is over 25 years old and was constructed without a stabilized base course. An examination of the dowel bars obtained from several cores indicated that corrosion was very minor, hence there has been no significant reduction in bar thicknesses.) The slab faulting values in Table 3 also indicate the adequacy of the one-inch (2.5-cm) diameter dowel bars. Again, on the 30-foot (9.1-m) project less than 0.05 inches (1.3-mm) of slab faulting was measured. This is numerically equivalent to the slab faulting measured on the newer dowel bar projects with 20-foot (6.1-m) slabs and stabilized bases.

(6) Concrete pavements with the 20-foot (6.1-m) joint spacing are performing much better than those with the 58.5-foot (17.8-m) joint spacing, regardless of the type of load transfer device used. The shorter slabs had less faulting, less pavement growth, better load transfer capability across joints, and less transverse cracking, corner cracking, corner breakout and patching.

Based on the above findings, it is recommended that:

(1) The distress mechanisms used to evaluate the two load transfer devices be correlated with the maintenance efforts required on projects containing these devices.

(2) An effort be directed to the continued evaluation of the devices for 20-foot (6.1-m) slabs.

(3) The two primary methods of installing the devices (mechanical and hand placement) be compared to determine the most effective method of placement.

(4) Dowel bars be one inch (2.5-cm) in diameter and 18 inches (45.7-cm) in length.

(5) Consideration be given to the FHWA recommendations as to placement and tolerances of dowel bars. The recommendations are that:

(a) Dowel bars be placed on 12-inch (30.5-cm) centers at mid-depth of the slab with a tolerance of placement within ± one inch (2.5-cm) of the planned lateral and vertical positions.

(b) Dowel bars be placed parallel to the centerline and surface of the slab and that the tolerance of this placement be within ± 1/4 inch (0.6-cm) per 18-inch (45.7-cm) dowel.

(c) The free ends of dowel bars be saw cut and free of burs or projections that would restrict movement.

REFERENCES

1. Pace, George M. Evaluation of the Dynaflect for the Non-Destructive Testing of Portland Cement Concrete Pavement. Technical Report No. 4-61, Department of the Army, Ohio River Division Laboratories, Corps of Engineers, August 1967.

2. Peterson, Gordon and Wayne L. Shepherd. Deflection Analysis of Flexible Pavements. Utah State Highway Department, January 1972.

3. Pace, George M. Non-Destructive Tests for Rigid Pavements Using Dynamic Deflection Measurements. U. S. Army Engineer Division, Ohio River, December 1967.

4. Majidzadeh, Kamran. Dynamic Deflection Study for Pavement Condition Investigation. Ohio Department of Transportation, June 1974.

APPENDIX

TABLE 5

LOAD TRANSFER EVALUATION BY PRODUCT AND LOT

(SEE NOTE BELOW FOR EXPLANATION OF COLUMN HEADINGS)

PROD	LOT	CUST	UTW	AIRT	SPRT	[illegible]	MDIF	AVGDIF	STS1	STS2	[illegible]	I	[illegible]	[illegible]	T20RK	T30RK	T40RK	T50RK
1	1	DB	.52	75	70	.002	.008	.004	0.75	.68	.01	.12	.07	1805	0	68	0	0
1	2	DB	.52	76	71	.001	.012	.005	0.84	.70	.01	.38	.13	3601	0	9	0	18
1	3	DB	.59	72	65	.002	.016	.007	0.92	.59	.08	.67	.33	3394	0	18	0	9
1	4	DB	.58	76	65	.001	.009	.005	0.66	.54	.07	.22	.12	2879	0	0	0	5
1	5	DB	.52	75	70	.001	.008	.004	0.87	.65	.06	.44	.22	3010	0	0	0	0
1	6	DB	.54	77	72	.002	.006	.004	0.83	.65	.03	.44	.18	1733	0	0	0	0
2	1	SL	.59	68	65	.004	.018	.012	0.58	.25	.00	.36	.73	898	0	0	0	0
2	2	SL	.54	68	65	.007	.025	.017	0.78	.59	.05	.43	.19	875	0	14	0	5
2	3	SL	.52	68	65	.003	.022	.014	0.68	.61	.00	.28	.07	672	0	0	0	5
2	4	SL	.51	66	65	.001	.013	.007	0.53	.49	.20	.64	.43	144	0	0	0	50
2	5	SL	.54	68	65	.002	.014	.007	0.74	.59	.01	.39	.15	533	0	0	0	0
2	6	SL	.59	68	65	.002	.011	.007	0.80	.40	.20	.64	.35	663	5	0	81	0
3	1	DB	.51	74	65	.001	.009	.004	0.74	.46	.15	.47	.28	429	0	54	0	0
3	2	DB	.51	74	65	.000	.008	.003	0.65	.53	.01	.43	.12	393	0	45	0	104
3	3	DB	.53	74	65	.000	.022	.004	0.55	.46	.01	.25	.09	921	0	50	0	0
3	4	DB	.60	74	65	.000	.005	.002	0.62	.44	.09	.42	.18	785	0	0	0	0
3	5	DB	.52	74	65	.001	.008	.003	0.70	.50	.09	.51	.20	325	0	0	108	0
3	6	DB	.51	74	65	.001	.006	.003	0.60	.50	.00	.26	.16	334	0	0	0	5
4	1	SL	.48	82	81	.004	.015	.011	0.60	.43	.01	.20	.12	626	0	0	0	302
4	2	SL	.49	82	81	.004	.019	.012	0.66	.51	.04	.25	.15	217	0	0	0	5
4	3	SL	.48	82	81	.006	.018	.012	0.67	.55	.03	.18	.12	1006	0	18	0	181
4	4	SL	.53	82	81	.002	.023	.007	0.75	.33	.30	.53	.42	970	0	18	0	0
4	5	SL	.50	82	81	.003	.011	.006	0.63	.48	.04	.22	.15	375	0	0	0	0
4	6	SL	.51	82	81	.003	.010	.005	0.59	.40	.02	.35	.19	523	68	0	0	5
5	1	DB	.55	74	74	.002	.014	.005	1.11	.78	.13	.55	.34	0	0	0	0	0
5	2	DB	.56	74	74	.001	.013	.005	1.19	.74	.17	.77	.45	451	0	0	0	9
5	3	DB	.55	74	74	.002	.012	.007	0.80	.67	.07	.26	.13	23	0	0	0	0
5	4	DB	.53	74	74	.002	.014	.007	0.77	.64	.05	.24	.15	54	0	0	0	0

TABLE 5 (CONTINUED)

LOAD TRANSFER EVALUATION BY PROJECT AND LOT

PROJ	LOT	LDDT	JTW	AIRT	SRFT	LDIF	HDIF	AVGDIF	SNS1	SNS2	LSCI	HSCI	AVGSCI	T1CRK	T2CRK	T3CRK	T4CRK	T5CRK
5	5	DB	.52	74	74	.001	.023	.004	.75	.56	.10	.31	.18	135	0	0	0	0
5	6	DB	.52	74	74	.001	.005	.003	.70	.54	.06	.29	.16	0	0	0	0	0
6	1	SL	.51	68	67	.001	.017	.009	.58	.45	.07	.23	.13	2401	9	0	0	5
6	2	SL	.50	66	67	.002	.014	.007	.59	.48	.01	.24	.11	1458	0	0	0	0
6	3	SL	.59	68	67	.003	.022	.008	.72	.55	.10	.23	.18	1011	0	0	0	0
6	4	SL	.56	68	67	.002	.012	.006	.64	.54	.02	.17	.10	1056	0	0	0	0
6	5	SL	.51	68	67	.003	.054	.010	.65	.53	.04	.19	.12	1435	0	5	0	0
6	6	SL	.50	68	67	.001	.026	.006	.66	.53	.07	.19	.13	2333	18	0	0	0
7	1	CB	.64	69	66	.000	.009	.004	.90	.73	.12	.30	.17	140	0	27	0	0
7	2	DB	.57	69	66	.001	.012	.004	.91	.72	.10	.30	.19	298	0	0	0	0
7	3	DB	.76	69	66	.001	.023	.011	.80	.70	.05	.18	.10	77	9	0	0	0
7	4	CB	.71	69	66	.004	.020	.011	.81	.67	.07	.26	.14	0	0	0	0	0
7	5	DB	.56	69	66	.001	.009	.004	.81	.64	.11	.28	.17	90	0	0	0	0
7	6	CB	.62	69	66	.000	.007	.004	.68	.58	.05	.17	.10	162	0	18	0	0
8	1	SL	.55	70	67	.001	.010	.004	.82	.47	.15	.48	.35	2184	9	27	0	0
8	2	SL	.55	70	67	.002	.019	.005	.95	.47	.12	.79	.49	2626	5	0	0	45
8	3	SL	.54	70	67	.002	.011	.005	.82	.33	.07	.66	.49	1801	18	0	0	18
8	4	SL	.49	70	67	.001	.014	.005	.65	.50	.08	.21	.14	2031	9	0	0	0
8	5	SL	.50	70	67	.000	.007	.003	.70	.53	.06	.24	.16	2329	36	0	0	0
8	6	SL	.50	70	67	.001	.008	.003	.69	.53	.10	.24	.16	1895	45	0	0	0
9	1	DB	.64	75	73	.000	.006	.003	.48	.41	.00	.16	.07	0	0	104	0	0
9	2	DB	.53	75	73	.002	.015	.007	.59	.46	.05	.32	.12	0	5	90	0	9
9	3	DB	.72	75	73	.001	.013	.006	.66	.46	.00	.34	.19	54	113	199	0	45
9	4	DB	.60	75	73	.001	.009	.003	.66	.50	.08	.24	.17	0	0	27	0	776
9	5	DB	.53	75	73	.002	.010	.005	.66	.45	.11	.36	.21	217	0	14	0	754
9	6	DB	.51	75	73	.001	.006	.003	.56	.39	.09	.32	.17	0	9	54	0	0
10	1	SL	.48	86	102	.002	.032	.011	.56	.48	.04	.21	.09	185	59	199	0	505
10	[illegible]	SL	.4[illegible]	[illegible]	102	[illegible]	[illegible]	.032	.47	.38	.01	.07	.09	0	68	144	0	627

TABLE 5 (CONTINUED)

LOAD TRANSFER EVALUATION BY PROJECT AND LCT

PROJ	LCT	LDOT	JTW	AIRT	SRFT	LDIF	HDIF	AVGDIF	SNS1	SNS2	LSCI	HSCI	AVGSCI	T1CRK	T2CRK	T3CRK	T4CRK	T5CRK
10	3	SL	.60	86	102	.002	.021	.010	0.70	0.57	.04	.46	.13	465	108	131	0	343
10	4	SL	.56	86	102	.002	.015	.007	0.69	0.59	.01	.29	.10	162	0	0	0	0
10	5	SL	.41	86	102	.004	.034	.012	0.40	0.36	.01	.08	.04	81	9	0	0	0
10	6	SL	.41	86	102	.002	.016	.007	0.60	0.49	.05	.30	.11	9	45	90	0	0
11	1	DB	.58	79	95	.002	.026	.007	0.54	0.46	.04	.22	.08	0	41	397	0	50
11	2	DB	.57	79	95	.001	.014	.006	0.49	0.42	.03	.14	.07	0	135	27	0	0
11	3	DB	.76	79	95	.003	.019	.008	0.74	0.55	.02	.51	.19	375	90	27	0	487
11	4	DB	.68	79	95	.002	.009	.005	0.66	55	.05	.17	.11	217	0	14	0	496
11	5	DB	.55	79	95	.001	.007	.004	0.54	0.44	.06	.14	.10	0	0	14	0	0
11	6	DB	.57	79	95	.000	.008	.004	0.55	0.46	.05	.13	.09	0	0	542	0	0
12	1	SL	.42	79	84	.005	.024	.010	0.59	0.37	.02	.40	.22	293	45	126	0	280
12	2	SL	.46	79	84	.003	.034	.014	0.48	0.28	.00	.45	.19	302	90	496	0	1101
12	3	SL	.74	79	84	.002	.033	.013	0.86	0.55	.10	.54	.31	469	27	171	0	740
12	4	SL	.65	79	84	.004	.016	.008	0.69	0.56	.04	.30	.13	316	0	108	0	821
12	5	SL	.43	79	84	.001	.024	.008	0.49	0.44	.02	.08	.05	108	0	99	0	63
12	6	SL	.47	79	84	.003	.016	.010	0.62	0.48	.02	.29	.14	117	36	23	0	41
13	1	DB	.59	82	96	.002	.041	.010	0.60	0.44	.05	.38	.15	99	86	63	0	86
13	2	DB	.65	82	96	.004	.016	.010	0.45	0.29	.07	.30	.16	415	153	63	0	181
13	3	DB	.53	82	96	.003	.019	.010	0.55	0.45	.06	.19	.10	402	5	0	0	99
13	4	DB	.54	82	96	.003	.013	.007	0.51	0.42	.06	.15	.09	271	9	0	0	9
13	5	DB	.56	82	96	.002	.016	.007	0.43	0.32	.06	.26	.12	208	32	226	0	18
13	6	DB	.57	82	96	.002	.012	.006	0.56	0.45	.05	.17	.11	27	104	230	0	18
14	1	SL	.66	83	89	.001	.023	.007	0.63	0.40	.04	.50	.23	266	45	162	0	519
14	2	SL	.73	83	89	.003	.023	.010	0.64	0.41	.10	.39	.23	591	176	659	0	325
14	3	SL	.78	83	89	.001	.015	.007	0.63	0.35	.00	.56	.22	402	95	239	0	988
14	4	SL	.69	83	89	.000	.024	.006	0.54	0.40	.10	.21	.14	126	14	131	0	86
14	5	SL	.67	83	89	.001	.015	.009	0.60	0.43	.03	.30	.18	126	59	18	0	149
14	6	SL	.60	83	89	.000	.005	.003	0.58	0.45	.02	.30	.13	[illegible]	0	203	0	54

TABLE 5 (CONTINUED)

LOAD TRANSFER EVALUATION BY PROJECT AND LOT

PROJ	LOT	LDOT	JTW	AIRT	SRFT	LCIF	HCIF	AVGCIF	SNS1	SNS2	LSCI	HSCI	AVGSCI	T1CRK	T2CRK	T3CRK	T4CRK	T5CRK
15	1	CB	.47	87	99	.003	.021	.010	0.56	0.48	.04	0.13	0.08	108	63	131	0	153
15	2	CB	.49	87	99	.004	.020	.009	0.45	0.36	.06	0.16	0.09	50	41	81	0	63
15	3	DB	.76	87	99	.001	.020	.005	0.75	0.32	.05	0.86	0.43	54	59	36	0	41
15	4	DB	.71	87	99	.002	.020	.008	0.64	0.42	.12	0.35	0.23	0	0	0	0	0
15	5	DB	.50	87	99	.002	.013	.007	0.43	0.35	.05	0.14	0.08	0	108	208	0	14
15	6	DB	.49	87	99	.001	.012	.005	0.55	0.47	.06	0.13	0.08	162	27	108	0	18
16	1	SL	.64	89	102	.002	.023	.009	0.61	0.46	.05	0.46	0.15	465	126	63	0	614
16	2	SL	.67	89	102	.001	.008	.003	0.53	0.40	.06	0.36	0.12	1354	0	90	0	32
16	3	SL	.76	89	102	.002	.046	.011	0.76	0.36	.00	0.83	0.35	68	59	117	0	857
16	4	SL	.71	89	102	.000	.027	.006	0.50	0.38	.05	0.21	0.11	99	0	36	0	199
16	5	SL	.55	89	102	.001	.005	.002	0.48	0.37	.06	0.19	0.11	54	0	68	0	14
16	6	SL	.61	89	102	.002	.014	.007	0.54	0.44	.07	0.17	0.10	325	9	0	0	0
17	1	CB	.65	57	58	.001	.011	.005	0.57	0.43	.04	0.23	0.14	0	5	135	0	9
17	2	CB	.65	57	58	.002	.021	.007	0.60	0.50	.03	0.38	0.10	623	9	86	0	1110
17	3	DB	.61	57	58	.001	.023	.006	0.61	0.56	.01	0.20	0.05	808	9	72	0	379
17	4	CB	.59	57	58	.000	.011	.005	0.69	0.55	.08	0.60	0.14	329	9	0	0	379
17	5	DB	.64	57	58	.001	.011	.006	0.60	0.52	.01	0.13	0.08	596	32	14	0	1106
17	6	CB	.64	57	58	.001	.022	.004	0.57	0.50	.01	0.16	0.07	0	9	162	0	27
18	1	SL	.85	62	68	.005	.020	.013	0.93	0.73	.10	0.33	0.20	0	0	0	0	0
18	2	SL	.61	62	68	.004	.023	.012	0.59	0.55	.01	0.08	0.04	406	18	402	0	63
18	3	SL	.55	62	68	.004	.022	.012	0.74	0.66	.01	0.47	0.08	0	0	0	0	0
18	4	SL	.59	62	68	.003	.012	.006	0.93	0.49	.10	0.67	0.44	0	0	0	0	0
18	5	SL	.59	62	68	.004	.015	.008	0.65	0.52	.02	0.30	0.13	194	18	27	0	59
18	6	SL	.76	62	68	.004	.015	.009	0.84	0.68	.04	0.31	0.16	0	0	0	0	0
19	1	CB	.54	69	67	.003	.017	.007	0.63	0.51	.01	0.39	0.12	325	95	63	0	113
19	2	DB	.67	69	67	.003	.017	.007	0.69	0.54	.05	0.31	0.14	429	0	14	0	397
19	3	CB	.89	69	67	.004	.017	.009	0.80	0.50	.17	0.53	0.29	1241	5	0	0	903
19	4	DB	.62	69	67	.001	.015	.007	0.74	0.57	.05	0.25	0.16	1331	[illegible]	68	0	812

TABLE 5 (CONTINUED)

LEAD TRANSFER EVALUATION BY PROJECT AND LOT

PROJ	LOT	LJDT	JTW	AIRT	SRFT	LDIF	HDIF	AVGDIF	SNS1	SNS2	LSCI	HSCI	AVGSCI	T1CRK	T2CRK	T3CRK	T4CRK	T5CRK
19	5	DB	.61	69	67	.001	.014	.008	0.68	0.56	.07	0.19	0.13	149	0	0	0	9
19	6	DB	.55	69	67	.001	.011	.005	0.59	0.51	.02	0.15	0.08	108	0	0	0	41
20	1	SL	.66	65	68	.002	.016	.011	0.61	0.57	.01	0.05	0.03	108	18	81	0	9
20	2	SL	.53	65	68	.007	.021	.012	0.67	0.56	.04	0.19	0.11	0	23	90	0	0
20	3	SL	.54	65	68	.004	.017	.011	0.86	0.54	.12	0.49	0.32	190	9	77	0	36
20	4	SL	.49	65	68	.004	.012	.007	0.79	0.57	.09	0.40	0.23	162	14	199	0	9
20	5	SL	.48	65	68	.002	.016	.009	0.71	0.52	.09	0.42	0.15	0	0	217	0	23
20	6	SL	.65	65	68	.002	.015	.008	0.60	0.57	.01	0.07	0.04	108	5	0	0	9
21	1	CB	.63	70	74	.001	.009	.004	1.49	1.26	.03	0.87	0.23	0	0	766	0	1690
21	2	CB	.63	70	74	.001	.006	.004	1.46	1.19	.09	0.72	0.27	0	18	326	0	0
21	3	DB	.47	70	74	.001	.020	.004	1.42	1.27	.02	0.57	0.15	0	44	528	0	62
21	4	CB	.60	71	80	.001	.008	.004	1.32	1.18	.03	0.24	0.13	0	0	282	0	0
21	5	CB	.67	71	80	.001	.008	.004	1.34	1.20	.06	0.24	0.14	0	0	290	0	9
21	6	CB	.70	71	80	.001	.013	.005	1.37	1.26	.03	0.18	0.12	0	0	229	0	634
22	1	SL	.58	61	69	.007	.026	.018	2.72	1.31	.18	2.04	1.41	2218	0	0	0	317
22	2	SL	.50	61	69	.006	.029	.014	3.47	1.63	.87	2.80	1.84	4330	0	0	0	0
22	3	SL	.45	61	69	.017	.041	.027	2.62	1.22	.60	2.03	1.40	1795	0	0	0	2578
22	4	SL	.40	61	69	.008	.018	.013	2.77	1.36	.18	2.49	1.42	3379	79	0	0	0
22	5	SL	.46	61	69	.002	.014	.008	3.32	1.65	.51	2.50	1.66	4365	282	0	0	0
22	6	SL	.53	61	69	.005	.018	.011	2.68	1.44	.39	1.95	1.25	4682	176	0	0	0
23	1	CB	.41	53	57	.001	.005	.003	1.44	0.81	.47	1.00	0.62	0	0	26	0	26
23	2	CB	.42	53	57	.001	.007	.003	1.22	0.63	.35	0.75	0.59	0	0	92	0	0
23	3	CB	.42	53	57	.001	.007	.003	1.16	0.75	.39	0.46	0.42	0	0	449	0	13
23	4	CB	.39	55	59	.001	.006	.002	1.21	0.77	.31	0.51	0.43	0	0	172	0	13
23	5	CB	.42	55	59	.001	.005	.003	1.17	0.66	.31	0.71	0.51	0	0	0	0	0
23	6	DB	.40	55	59	.000	.004	.002	1.33	0.80	.41	0.66	0.54	0	0	0	0	0
24	1	SL	.55	45	52	.002	.016	.007	1.03	0.65	.27	0.42	0.38	0	0	752	0	26
24	2	SL	.61	45	52	.001	.011	.005	1.56	0.74	.43	1.37	0.82	0	0	145	0	13

TABLE 5 (CONTINUED)

LOAD TRANSFER EVALUATION BY PROJECT AND LCT

PROJ	LCT	LDJT	JTW	AIRT	SRFT	LDIF	HDIF	AVGDIF	SNS1	SNS2	LSCI	HSCI	AVGSCI	T1CRK	T2CRK	T3CRK	T4CRK	T5CRK
24	3	SL	.58	45	52	.001	.014	.006	1.34	0.65	.49	.87	.65	0	13	185	0	26
24	4	SL	.58	47	57	.001	.008	.003	1.12	0.63	.37	.60	.49	0	13	436	0	53
24	5	SL	.60	47	57	.002	.009	.004	1.27	0.66	.36	.90	.59	0	13	26	0	185
24	6	SL	.57	47	57	.001	.010	.004	1.14	0.74	.33	.47	.40	0	13	528	0	488
25	1	DB	.46	87	107	.001	.008	.004	0.80	0.78	.00	.06	.02	0	0	0	0	0
25	2	DB	.39	80	107	.001	.009	.005	1.19	1.14	.03	.09	.05	0	0	53	0	0
25	3	DB	.32	80	101	.001	.012	.005	0.68	0.63	.03	.06	.05	0	13	0	0	0
25	4	DB	.33	80	101	.001	.011	.004	0.71	0.66	.03	.10	.05	0	0	238	0	0
25	5	DB	.40	80	107	.000	.005	.003	1.21	1.17	.03	.09	.04	0	0	0	0	0
25	6	DB	.44	87	107	.001	.005	.003	0.84	0.82	.01	.03	.02	0	0	594	0	0
26	1	SL	.52	97	133	.002	.014	.006	0.71	0.64	.05	.09	.06	0	0	172	0	53
26	2	SL	.51	97	133	.000	.012	.006	0.66	0.60	.04	.08	.06	0	0	686	0	0
26	3	SL	.56	97	133	.000	.010	.006	0.65	0.61	.03	.07	.05	0	0	0	0	13
26	4	SL	.53	97	133	.001	.011	.005	0.58	0.56	.01	.08	.02	0	0	40	0	26
26	5	SL	.51	97	133	.001	.008	.004	0.59	0.57	.00	.04	.02	0	0	13	0	0
26	6	SL	.49	97	133	.001	.010	.005	0.69	0.66	.02	.04	.03	0	0	40	0	40
27	1	DB	.43	91	105	.000	.004	.002	0.79	0.77	.01	.04	.02	0	0	106	0	0
27	2	DB	.45	91	105	.000	.010	.002	0.71	0.68	.01	.04	.02	158	0	0	0	0
27	3	DB	.44	91	105	.000	.006	.003	0.78	0.76	.01	.04	.02	0	0	0	0	0
27	4	DB	.45	91	105	.000	.007	.003	0.78	0.76	.01	.03	.02	0	0	13	0	0
27	5	DB	.48	91	105	.000	.005	.002	0.77	0.76	.01	.06	.02	158	0	0	0	0
27	6	DB	.48	91	105	.000	.003	.002	0.81	0.78	.01	.04	.03	0	0	26	0	0
28	1	SL	.49	90	110	.001	.006	.004	0.46	0.43	.01	.05	.03	0	0	0	0	0
28	2	SL	.50	90	110	.002	.006	.003	0.48	0.45	.01	.12	.03	0	0	0	0	0
28	3	SL	.52	90	110	.001	.009	.004	0.52	0.49	.01	.09	.03	0	13	0	0	0
28	4	SL	.47	90	110	.002	.016	.004	0.48	0.45	.01	.05	.02	0	0	0	0	0
28	5	SL	.48	90	110	.001	.008	.004	0.50	0.47	.01	.05	.02	0	0	0	0	0
28	6	SL	.48	90	110	.001	.005	.003	0.49	0.47	.01	.04	.02	0	0	0	0	0

TABLE 5 (CONTINUED)

LOAD TRANSFER EVALUATION BY PROJECT AND LOT

PROJ	LOT	LDDT	JTW	AIRT	SRFT	LOIF	HOIF	AVGDIF	SNS1	SNS2	LSCI	HSCI	AVGSCI	T1CRK	T2CRK	T3CRK	T4CRK	T5CRK
29	1	DB	.43	88	112	.001	.020	.008	.79	.73	.04	.10	.06	0	0	53	0	0
29	2	DB	.42	92	120	.003	.024	.009	.65	.59	.03	.09	.06	0	0	53	0	13
29	3	DB	.40	90	121	.002	.013	.006	.72	.68	.02	.06	.04	0	0	0	0	0
29	4	DB	.37	90	121	.001	.008	.004	.70	.66	.02	.06	.04	0	0	26	0	0
29	5	DB	.44	86	116	.002	.007	.004	.67	.63	.04	.07	.05	0	0	26	0	0
29	6	DB	.42	90	119	.001	.016	.005	.73	.66	.04	.10	.07	0	0	185	0	0
30	1	SL	.38	89	116	.001	.011	.005	.72	.68	.01	.16	.04	0	0	0	0	0
30	2	SL	.38	89	116	.001	.013	.006	.79	.74	.01	.51	.05	0	0	79	0	0
30	3	SL	.39	91	120	.001	.009	.005	.84	.77	.01	.31	.07	0	53	106	0	0
30	4	SL	.46	92	123	.001	.009	.005	.80	.77	.01	.12	.03	0	0	0	0	0
30	5	SL	.47	92	123	.002	.009	.005	.80	.77	.01	.09	.03	0	0	0	0	462
30	6	SL	.43	89	116	.001	.014	.004	.73	.70	.00	.06	.02	0	0	0	0	1003
31	1	DB	.41	82	102	.001	.007	.003	.85	.82	.01	.09	.03	0	26	0	0	0
31	2	DB	.48	83	102	.000	.011	.004	.83	.79	.00	.09	.03	0	0	0	0	0
31	3	DB	.42	82	102	.000	.006	.003	.87	.83	.02	.24	.04	0	0	0	0	0
31	4	DB	.43	89	115	.001	.007	.004	.96	.90	.03	.12	.06	0	0	0	0	13
31	5	DB	.49	89	115	.001	.011	.004	.79	.75	.02	.07	.04	0	0	0	0	13
31	6	DB	.44	89	115	.001	.010	.004	.87	.82	.02	.12	.06	0	0	0	0	0

N=186

NOTE: PROJ - PROJECT NUMBER
LOT - LOT NUMBER
LDDT - LOAD TRANSFER DEVICE
DB - DOWEL BAR
SL - STAR LUG
JTW - JOINT WIDTH (IN)
AIRT - AIR TEMPERATURE (F)
SRFT - SURFACE TEMPERATURE (F)
LOIF - MINIMUM FAULTING (FT)
HOIF - MAXIMUM FAULTING (FT)
DIF - FAULTING (FT)
SNS1 - SENSOR 1 (MILLI-INCH)
SNS2 - SENSOR 2 (MILLI-INCH)
LSCI - MINIMUM SCI (MILLI-INCH)
HSCI - MAXIMUM SCI (MILLI-INCH)
SCI - SURFACE CURVATURE INDEX (MILLI-INCH)
T1CRK - TRANSVERSE CRACKING (FT/LANE-MILE)
T2CRK - CORNER CRACKING (FT/LANE-MILE)
T3CRK - PERPENDICULAR JOINT CRACKING (FT/LANE-MILE)
T4CRK - LONGITUDINAL CRACKING (FT/LANE-MILE)
T5CRK - PATCHING AND/OR CORNER BREAKOUT (SQ FT/LANE-MILE)

FIGURE 18

RESEARCH & DEVELOPMENT SECTION
QUESTIONNAIRE ON USE OF LOAD TRANSFER DEVICES

1. Approximate number of concrete paving jobs you have been associated with? ______________

   A. Formed ______________
   B. Slip-Formed ______________
   C. C.R.C.P. ______________

2. Approximate number of these jobs were:

   Starlugs ______________
   Dowel Bars ______________

3. Which has given you the most trouble? ______________

4. What trouble have you encountered with each? ______________

____

____

____

____

5. Which do you prefer to use? ______________

6. Why? ______________

____

____

____

____

7. Other Comments: ______________

____

____

____

____

TABLE 6

LOCATION OF TEST SECTIONS

PROJECT I.D. NO.	STATE ROUTE	STATE PROJECT NO.	LOCATION
1 (Eastbound) 3 (Westbound)	I-10	450-02-26	Begins 0.10 miles east of mile post #44 and continues for 3.30 miles
2 (Eastbound) 4 (Westbound)	I-10	450-02-25	Begins 5.15 miles east of mile post #44 and continues for 3.80 miles
6 (Eastbound) 8 (Westbound)	I-210	450-30-06	Test sections located between I-10 and the I-210 bridge
5 (Eastbound) 7 (Westbound)	I-210	450-30-07	Begins east of I-210 bridge and continues for approximately two miles
9 (Eastbound) 11 (Westbound)	I-20	740-00-25	Begins 0.03 miles east of mile post #94 and continues for 3.09 miles
10 (Eastbound) 12 (Westbound)	I-20	740-00-26	Begins 0.17 miles east of mile post #99 and continues for approximately 3 miles
13 (Eastbound) 15 (Westbound)	I-20	740-00-21	Begins 0.89 miles east of mile post #86 and ends 0.79 miles east of mile post #88
14 (Eastbound) 16 (Westbound)	I-20	740-00-22	Begins 0.94 miles east of mile post #89 and ends 0.45 miles east of mile post #92
17 (Eastbound) 19 (Westbound)	US-167	424-01-01	Begins 3.10 miles north of Jct. US-167 & La. 93 and continues north for 3.67 miles
18 (Eastbound) 20 (Westbound)	US-167	424-02-12	Begins 4.80 miles north of the T&NO Railroad crossing and continues for 2.70 miles
21 (Both Lanes)	La.23	62-02-13	Begins 1.28 miles north of mile post #49 and ends at mile post #49
22 (Both Lanes)	La.55	248-03-04	Begins 0.2 miles south of mile post #12 and continues south to mile post #15
23 (Westbound)	US-65	26-02-19	Begins at mile post #5 and continues west for 0.34 miles
24 (Westbound)	US-65	26-02-23	Begins 0.61 miles east of mile post #8 and continues west for approximately one mile
25 (Both Lanes)	US-61	252-01-03	Begins 0.37 miles north of Missouri Pacific Railroad Crossing and continues north for 4.66 miles
26 (Northbound)	La.165 (4-lane)	15-31-03	Test sections are located between La.15 and Powell Avenue

PROJECT I.D.NO.	STATE ROUTE	STATE PROJECT NO.	LOCATION
27 (Both Lanes)	US-65 (2-lane)	20-06-17	Begins 1.40 miles south of Alligator Bayou Bridge and continues south for approximately one mile
28 (Eastbound)	I-10	450-06-01	Test sections are located immediately west of the Henderson Interchange
29 (Westbound)	US-190	12-13-34	Begins 1.85 miles west of the Bayou Tech Bridge in Port Barre and continues west for approximately 1.50 miles
30 (Both Lanes)	US-165 (2-lane)	15-31-02	Test sections are located between La.15 and the US-165 bypass
31 (Westbound)	US-190	12-13-35	Begins 0.51 miles west of the Bayou Courtableau Bridge and continues for approximately 0.30 miles